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# CALCULATION MODEL FOR THE CONSUMED AIR FLOW BY A LINEAR ACTUATOR

**Ștefan Ionuţ CRĂCIUN, Ionuţ Adrian CHIŞ, Anca SÂRB**

***Abstract:*** *In the automation of industrial area, lately we notice a more pronounced use of pneumatic actuators. In the case of pneumatic actuators the primary energy source is converted into pneumatic energy, using a compressor, which is then supplied to a pneumatic motor (linear or cylindrical pneumatic actuator). For more accurately balance of energy and high efficiency of pneumatic system an important role represent the actuator sizing. More precisely it is about determination of flow air that is consume by the actuator and the pressure required in the system.*

***Key words:*** *dimensioning, compressed air, consumption, pressure, flow*

## 1. INTRODUCTION

Today pneumatics is widespread in all areas of machine building (from simple mechanisms and to the complex automations): fastening devices in execution and assembly , machines of packing in light and food industries, in foundries and mines, in the kinematics of machine tools and robots, up to realization of logical commands, achievable before only electronic.

The main advantages of pneumatic actuators are:

-The mixture of gases that is available to us is unlimited air. It is taken from the environment is compressed and, after the mechanical working, there is provided in the atmosphere.

-Energy storage capacity due to high compressibility of air;

-High speeds practicable in pipes (20...40m/s) due to the lower viscosity of air. Hence the possibility for a high-speed linear motor (1...6m/s), and rotating (turbine up to 150,000 $min^{-1}$). Air has a small mass, so low inertia;

-Possibility of using pneumatic networks, power supply due to low pressure loss;

-Permissiveness of easy commutability and without shocks for, thanks to high compressibility.

-Absence of danger of overloading, the pressure being limited to that network;

-Pneumatic actuation components are robust and reliable, insensitive to humidity and dust, and are not causing explosions in hazardous environments, allowing work in the wider field of temperature than liquid environments;

-From the ecological point of view does not "dirty" the installations and enclosures where is working.

Pneumatic actuator has disadvantages that must be taken into account when is deciding the type of actuation or when is designing this:

-The air pressurized is an expensive energy carrier because in most cases, work expanding of the air is not used. The yield may not exceed 0.15...0.2;

-Due to large energy storage capacity (risk of accidents) and from economic considerations, pressure network is limited to 6...10 bar. Therefore, the forces and moments developed by the engine is relatively low;

-Due to elastic behavior of actuation it is not possible to ensure uniform displacements (linear or rotary) at variable load;

-Amortization are reduced due to lower viscosity of air;

-Installations cost increases due to necessary compensation caused by condensation and ice formation in adiabatic depressurization;

-Noise vent (exhaust);

-Because air capacity is not lubricating installations require devices that ensure a mist oil in the flux.

## 2. DETERMINATION OF AIR FLOW FOR A LINIAR CYLINDER

In practice can be seen two parameters which refer to quantity of consumed air by a linear actuator like: medium volume flow ($Q_{mediu}$) and maximum volume flow ($Q_{max}$). These values are reported to normal reference atmosphere (NRA) characterized by a relative temperature $t_0 = 20^0$ C, atmospheric pressure $P_0$ = 1bar and relative humidity of 65%. The flow of a cylinder is related in meter cube per second ($m^3/s$).

For dimensioning of the compressor and for the estimation of the energetic costs wil be taken in consideration for calculus, always the medium flow ($Q_{med}$). The maximum flow ($Q_{max}$) will be used for dimensioning of equipment mounted on the pneumatic route (filter, regulator, distributor, pipes, actuators).

### 2.1. Calculus of medium flow

For calculating the medium flow is considering a pneumatic cylinder with double action and unilateral rod in the two extreme positions of the cylinder displacement:

- Position of advance – when the piston performs the forward stroke of its rod;
- Position of retracting – when the piston is retracted to the initial position.

In the next image are exemplified the two situations described later, on a cylinder with double action and unilateral rod.

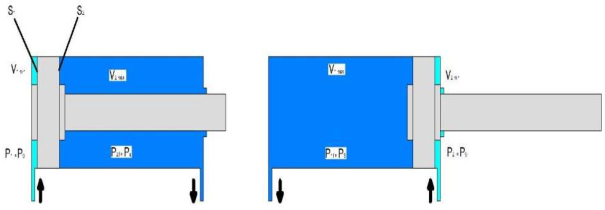

**Fig.1.** Defining of limit status for flow calculation

The volume $V_{1min}$ and $V_{2min}$ represent the internal volumes of the elements situated on the supply evacuation circuit between cylinder and distributor for which are added the "dead" volumes at the end of the course of piston, these minimum volumes can be determined by volume calculation starting from the internal overall dimensions of the pipes and the supply chamber.

In this situation the maximum volumes will be defined by the formula:

$$V_{1\,max} = V_{1min} + S_1 \cdot c \quad (1)$$

$$V_{2\,max} = V_{2min} + S_2 \cdot c \quad (2)$$

-where:S1 and S2 – the active surfaces of the piston for the two strokes;

c – the stroke of the piston.

For the simplified calculation is considering the simplified hypothesis so there are excluded the temperature variations (all the temperatures will be equal with the normal absolute temperature $t_0$), are considered the initial atmospheric pressures equal with normal atmospheric pressure ($P_{1i} = P_{2i} = P_0$ = 1 bar) and finale absolute pressures are equal to absolute pressure of the ($P_{1f} = P_{2f} = P_s$). Considering the simplifications explained above, the air consumption for double stroke will be:

$$\Delta V = (S_1 + S_2) \cdot c \cdot \frac{P_S}{P_0} + (V_{1min} + V_{2min}) \cdot (\frac{P_S}{P_0} - 1) \quad (3)$$

$$\Delta V_{cylinder} = (S_1 + S_2) \cdot c \cdot \frac{P_S}{P_0} \quad (4)$$

$$\Delta V_{pipes} = (V_{1min} + V_{2min}) \cdot (\frac{P_S}{P_0} - 1) \quad (5)$$

-where: $\Delta_V$ – air consumption for a double stroke;

$P_s$ – absolute pressure of the source;

$P_0$ – normal atmospheric pressure;

$V_{1min}$, $V_{2min}$ – minimum volumes of the pipes.

By geometric volume displaced Vg is meaning the sum of volume variations on a full cycle. For different types of linear pneumatic cylinders it is determined as:

$V_g = (S_1 + S_2) \cdot c$ - cylinders with double action and unilateral rod;
$V_g = 2 \cdot S \cdot c$ - cylinders with double action and unilateral rod ($S=S_1=S_2$);
$V_g= S_1 \cdot c$ - cylinders with simple pushing action;
$V_g = S_2 \cdot c$- cylinders with simple pulling action.

To take into account the variations of air temperature, in the calculation of the theoretic consumption is inserting a coefficient k=1.4 (experimentally determined) which will compensate the additional air volume required caused by the lowering of the air temperature to a high pressure.

Considering the supply gauge pressure $p=P_s-P_0$, and multiplying $\Delta_V$ with the number of cycles per minute ($n_c$) will obtain:

$$Q = k \cdot n_c \cdot [V_g \cdot (p+1) + V_t \cdot p] \quad \left[\frac{l}{min}\right] \quad (6)$$

where: $V_t$ – total volume of the pipes and supply chambers.

*Example of calculation:*

Find the air consumption for a cylinder with double action and unilateral rod, where are known: nominal diameter D = 60 mm, rod diameter d = 30 mm, stroke c = 400 mm, working pressure p = 6 bar, number of cycles per minute $n_c$ = 10. The cylinder is connected to the distributor with the help of two pipes with the total length l=3m and internal diameter di=6mm.

Solving:

The geometric volume of the cylinder will be:

$$V_g = (S_1 + S_2) \cdot c \quad (7)$$

$$V_g(28.27 + 21.20) \cdot 40 = 1978.9\, cm^3 \quad (8)$$

$$S_1 = \frac{\pi \cdot D^2}{4} = 28.27\ [cm^2] \quad (9)$$

$$S_2 = \frac{\pi \cdot (D^2 - d^2)}{4} = 21.20\ [cm^2] \quad (10)$$

The consumption on a double cycle will be:

$$\Delta_{V_1} = V_g \cdot (p+1) \cdot 10^{-3} \quad (11)$$

$$\Delta_{V_1} = 1978.9 \cdot 7 \cdot 10^{-3} = 13.85\ [l] \quad (12)$$

The interior volume of the pipes will be:

$$V_t = \frac{\pi \cdot d_i^2}{4} \cdot l \cdot 2 = 169.64\ [cm^3] \quad (13)$$

Air consumption due to the pipes will be:

$$\Delta_{V_2} = V_t \cdot p \cdot 10^{-3} \quad (14)$$

$$\Delta_{V_2} = 169.64 \cdot 6 \cdot 10^{-3} = 1.017\ [l] \quad (15)$$

Total consumption on a cycle:

$$\Delta V = \Delta V_1 + \Delta V_2 =$$

$$\Delta V = 13.85\ [l] + 1.017[l] = 14.867\ [l] \quad (16)$$

The average flow, if: k = 1.4 will be:

$$Q = k \cdot n_c \cdot \Delta V \quad (17)$$

$$Q = 1.4 \cdot 10 \cdot 14.867 = 208.138\ [l/min]$$

If is considering that the equipment will work 16 hour/day, 6 days/week and 48 weeks/year, the annual air consumption will be:

$$Q_{year} = 208.14 \left[\frac{l}{min}\right] \cdot 60 \left[\frac{min}{h}\right] \cdot 16 \left[\frac{h}{day}\right] \cdot 6 \left[\frac{day}{week}\right] \cdot 48 \left[\frac{week}{year}\right] = 57\,546 \left[\frac{m^3}{year}\right] \quad (18)$$

**2.2. The calculation of maximum flow**

The calculation of the maximum flow will be determined when the product between active surface and displacement velocity (S·v), so for the advance stroke and also for retracting, will be maximum. The calculation relation for maximum flow, in this case will be:

$$Q_{max} = k \cdot S \cdot v \cdot (p+1) \cdot 6 \cdot 10^{-3} \left[\frac{l}{min}\right] (19)$$

where: $p = P_s - P_0$ - working pressure;
S – piston surface;
v - maximum velocity.

The product $S \cdot v$ will be considered the maximum between $S_1 \cdot v_1$ or $S_2 \cdot v_2$.

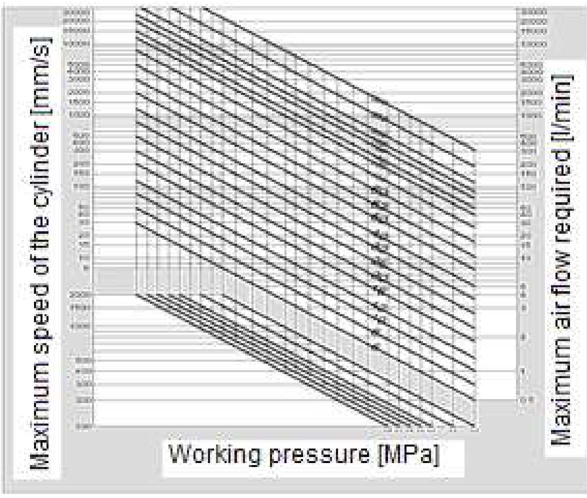


**Fig.2**. Graph for determining the maximum air flow.

For quick determination of makimum flow required, in the following lines is presented the diagram (the case when T is constant and k=1):

**Example of calculation**

Determine for the used cylinder in the above example, the maximum flow required if it develops an average travel speed per stroke 400 mm/s for both senses.

Solving:

The maximum flow consumption for advance stroke will be:

$$Q_{max} = k \cdot S_1 \cdot v \cdot (p+1) \cdot 6 \cdot 10^{-3} \quad (20)$$

$$Q_{max} = 1.4 \cdot 28.27 \cdot 400 \cdot 7 \cdot 6 \cdot 10^{-3} \quad (21)$$

$$Q_{max} = 664.91\ [l/min] \quad (22)$$

Here can be observed an increase of three times for the flow towards the average flow. During the dimensioning of pneumatic circuit components will be taken in calculation the value of maximum flow. Using the average flow, the chosen components will be undersized and will lead to a bad functioning of the designed system.

## 3. CONCLUSION

In this paper is presented a simple and quick modality through can be determined the average and maximum consumed flow by a linear cylinder. For determination of the two flows will be taken in calculation the dimensional characteristics of the cylinders (nominal diameter, rod diameter, stroke length, work pressure) and there are followed a series of steps presented in this paper.

Following steps for determination of average flow ($Q_{mediu}$) and maximum flow ($Q_{maxim}$) of a linear pneumatic cylinder having nominal diameter D=60mm, rod diameter d=30mm, stroke c=400mm, work pressure p=6bar, number of cycles $n_c$=10 were obtained the results:

- Average flow $Q_{mediu}$ = 208.138 [l/min];
- Annual consumption $Q_{an}$ = 57546 [m$^3$/an];
- Maximum flow $Q_{max}$ = 664.91 [l/min]

The average flow ($Q_{med}$) will be taken in consideration the dimensioning of the compressor and for cost of energetic estimation, and maximum flow ($Q_{max}$) will be used for dimensioning of equipment on the route (filter, regulator, distributor, pipes, actuators).

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**MODEL DE CALCUL AL DEBITULUI DE AER CONSUMAT DE UN ACTUATOR LINIAR**

*Rezumat: In domeniul automatizarilor din zona industriala, in ultima perioada se remarca o utilizare tot mai accentuata a actionarilor pneumatice. In cazul actionarilor pneumatice o sursa de energie primara este convertita in energie pneumatica, cu ajutorul unui compresor, care ulterior este furnizata unui motor penumatic (actuator pneumatic liniar sau cilindric). Pentru un echilibru energetic cat mai fidel si cu randament ridicat a sistemului pneumatic un rol important il reprezinta dimensionarea actuatorilor. Mai precis este vorba despre determinarea debitului de aer pe care actuatorul il consuma, precum si de presiunea necesara in sistem.*

**CRACIUN Stefan Ionuţ,** Assist. PhD. Eng., Technical University of Cluj-Napoca, Faculty of Machine Building, stefan.craciun@omt.utcluj.ro, shmef84@yahoo.com

**CHIS Ionuţ Adrian,** Sl. PhD. Eng., Technical University of Cluj-Napoca, Faculty of Machine Building, aionut84@yahoo.com

**SARB Anca,** PhD. Student, Technical University of Cluj-Napoca, Faculty of Machine Building, Anca.SARB@muri.utcluj.ro